

LIGHTING CALIFORNIA'S FUTURE: WIRELESS INTEGRATED PHOTOSENSOR AND MOTION SENSOR LIGHTING CONTROL SYSTEM



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Preface

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Lighting California's Future: Wireless Integrated Photosensor and Motion Sensor Lighting Control System is the final report for the Lighting California's Future project (Contract number 500-06-035 conducted by Architectural Energy Corporation, Adura Technologies, and the California Lighting Technology Center. The information from this project contributes to PIER's Building End-Use Energy Efficiency Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

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Abstract

Lighting California's Future was the California Energy Commission's \$3.7 million Public Interest Energy Research Program focused on lighting technologies for buildings. The Wireless Integrated Photosensor and Motion Sensor Lighting Control System project designed, developed, demonstrated, and commercialized an easy-to-install lighting system with low-power wireless communications to photo and motion sensors. The project team demonstrated the Wireless Integrated Photosensor and Motion Sensor system in both new construction and retrofit installations. Energy savings averaged 64 percent compared to the same lighting fixtures without controls under normal use. For California, this system can reduce installation and commission time by as much as 50 percent over standard industry practice for competing technologies and result in reducing lighting energy use in commercial applications.

Keywords: Lighting controls, wireless, occupancy sensing, photocell, WIPAM

Executive Summary

Introduction

The California Lighting the Future program, which began in May 2007, featured nine technical projects and a crosscutting market connections project. One of the nine technical projects was the Wireless Integrated Photosensor and Motion Sensor Lighting Control System. The Wireless Integrated Photosensor and Motion Sensor project team was composed of the California Lighting Technology Center and Adura Technologies.

Purpose

The Wireless Integrated Photosensor and Motion Sensor project sought to design, develop, demonstrate, and commercialize an easy-to-install lighting control system that adds low-power wireless communications capability to photo and motion sensors.

Project Objectives

Project objectives were to:

- Develop photo and motion sensors powered with low-power radios that are interoperable with wireless-luminaire-specific relays.
- Develop form factors and package sizes for photo and motion sensors that are non-invasive to building occupants.
- Develop algorithms that coordinate control signals among occupant detection, light level detection, and automated demand response.
- Establish application guidelines that foster best practices and reduce systemic error and installation time.
- Develop public specifications aimed at commercialization of wireless integrated photo and motion sensors and installation/operation guidelines.

Project Outcomes

Adura developed and commercialized a product that has brought innovative occupancy-based lighting control to the market.

The Wireless Integrated Photosensor and Motion Sensor system is expected to reduce installation and commissioning time by as much as 50 percent as compared to standard industry practice for competing lighting control technologies and could reduce open office lighting energy use by as much as 40 percent.

Field testing of the Wireless Integrated Photosensor and Motion Sensor system took place at the California Lighting Technology Center's facility in Davis, California, and in a parking garage at the University of California, Santa Barbara.

Field testing of the Wireless Integrated Photosensor and Motion Sensor system at the California Lighting Technology Center facility has demonstrated 64 percent energy savings as compared to energy used by the same fluorescent light fixtures without lighting controls under normal

work conditions. The project team installed the Wireless Integrated Photosensor and Motion Sensor system in two corridors at the California Lighting Technology Center facility: the classroom corridor (new construction) and the restroom corridor (retrofit). The demonstration system was commissioned for bilevel lighting (that is, fixtures commissioned to operate at two power levels and corresponding light levels to address both high and low occupancies). The ballasts in the demonstration have dimming capability, allowing the system to take advantage of daylight.

Tables 1 and 2 show the saving calculations for the California Lighting Technology Center field test (this field test purchased prototype components on a small scale, resulting in higher system costs than a commercially available product). Table 3 shows each corridor individually, which allows for comparison of occupancy rates. Lower-occupancy applications will save even more.

Table 1. Lighting energy use calculation

| Baseline | Fixture Wattage (kilowatt) | Number of Fixtures | Hours Per Day | Days Evaluated | kWh |
|-------------------|-----------------------------------|---------------------------|----------------------|-----------------------|------------|
| New Construction | 0.0325 | 7 | 10 | 3 | 6.83 |
| Retrofit | 0.0318 | 3 | 10 | 3 | 2.86 |
| | | | | Total: | 9.69 |
| W/Controls | Fixture Wattage (kW) | Number of Fixtures | Hours Per Day | Days Evaluated | kWh |
| New Construction | 0.0325 | 7 | 10 | 3 | 2.36 |
| Retrofit | 0.0318 | 3 | 10 | 3 | 1.17 |
| | | | | Total: | 3.53 |

Source: Architectural Energy Corporation

Table 2. Field test savings calculation

| Savings Calculations | (for the 10 demo fixtures) |
|-----------------------------|---|
| 2.05 | kWh saved for demo area/day |
| 492.70 | Annual kWh savings (Based on 240 workdays/year) |
| \$0.125 | Average kWh rate |
| \$61.59 | Annual savings |
| \$1,387.22 | System Cost |
| 63.58% | System Savings (Energy) |

Source: Architectural Energy Corporation

Table 3. Occupancy and vacancy related to savings

| Corridor | High Occupancy (70%) | Low Occupancy (30%) | Energy Savings |
|--------------------|-------------------------------------|------------------------------------|---------------------------|
| CLTC Demonstration | * | * | 63.6% |
| New Construction | 6.1% | 93.9% | 65.4% |
| Retrofit | 36.0% | 64.0% | 59.3% |

*From data – combined new construction and retrofit corridor data
Source: Architectural Energy Corporation

Conclusions

Innovative occupancy-based and daylight-responsive lighting controls can provide significant energy savings. Using a wireless control system can reduce the barriers to installation in existing buildings.

The field tests demonstrated innovative lighting control approaches that are highly applicable to existing buildings where retrofitting wired lighting controls would be cost prohibitive. The field tests demonstrated that the product offering is ready for commercial sales.

The field test at the California Lighting Technology Center demonstrated 64 percent energy savings in new construction and retrofit applications.

Recommendations

Adura should continue to look at opportunities to create a wireless occupancy sensor and a wireless photocell either through partnering with another manufacturer or creating these products themselves. The wireless products, while not applicable to all spaces, would further open opportunities for installing lighting controls in spaces that are challenging to install with wired devices.

Field testing identified some minor technological issues that need to be addressed, including ensuring that the system transitions from normal work settings to energy-saver settings regardless whether a space is occupied at the scheduled transition time.

Benefits to California

Benefits to California from commercialization of the Wireless Integrated Photosensor and Motion Sensor system include reduced start-up cost and improved reliability of commercial lighting controls, which would lead to their wider adoption and more reliable use. This wider adoption would substantially reduce lighting energy use in many challenging applications, including office buildings, warehouses, and parking garages.

1.0 Introduction

Lighting California's Future (LCF) was a \$3.7 million California Energy Commission Public Interest Energy Research (PIER) Program focused on lighting technologies for buildings. The program, which began in May 2007, featured nine technical projects and a crosscutting market connections project. One of the nine technical projects was the Wireless Integrated Photosensor and Motion Sensor (WIPAM) Lighting Control System. The California Lighting Technology Center and Adura Technologies comprised (made up) the project team.

1.1. Background

Lighting systems account for about 35% of the total average electrical use in California commercial buildings. Lighting control systems are broadly acknowledged as offering large, near-term opportunities to reduce this energy use. Traditional lighting control systems turn lights off when spaces are unoccupied or when sufficient daylight is available. These traditional control systems involve wiring, which can be an expensive proposition in existing buildings. A wireless lighting control system would simplify and reduce the cost of adding lighting controls to many buildings and, thus, greatly expand the number of buildings that could cost effectively reduce their lighting energy use.

Adura Technologies is a California-based startup company that is focused on creating wireless lighting controls. This approach includes controllers, sensors, switches, and other tools that simplify deployment and monitoring of lighting. From the beginning, it was believed that occupancy sensing and light level sensing were critical pieces of energy conserving lighting controls. However, neither type of device was integrated into the wireless lighting controls network in initial product offerings. This project was targeted to demonstrate how these vital components could be integrated into a wireless control network.

1.2. Project Objectives

Project objectives were to:

- Develop photo and motion sensors powered with low-power radios that are interoperable with wireless-luminaire-specific relays.
- Develop form factors and package sizes for photo and motion sensors that are non-invasive to building occupants.
- Develop algorithms that coordinate control signals among occupant detection, light level detection, and automated demand response.
- Establish application guidelines that foster best practice and reduce systemic error and installation time.
- Develop specifications aimed at commercialization of wireless integrated photo and motion sensors and installation/operation guidelines.

1.3. Benefits to California

Benefits to California from commercialization of the WIPAM system include reduced start-up cost and improved reliability of commercial lighting controls, which would lead to their wider

adoption and more reliable use. This would substantially reduce lighting energy use in new and existing buildings.

Applications for the system include small offices, corridors, and parking garages. The Adura team researched addressable floor space in various California commercial buildings. Team members calculated the addressable floor space for the WIPAM system to be 540 million square feet or 10% of floor stock. Using the amount of addressable floor space and assuming 5% market penetration with energy savings of 50%, the potential benefit is estimate to be more than 50 megawatt hours (MWh) per year. Demand savings are more difficult to assess since this technology is used to lower light levels during low or zero occupancy and return the lights to higher levels when presence is detected.

1.4. Commercialization Potential

Researchers found that presence detection could impact as much as 41.5% of California's floor space representing approximately 2.04 billion sq. ft. Daylighting controls are only good for about 355 million sq. ft., or about 7.2% of California floor space. The total size of the WIPAM market is about 540 million square feet but overlaps with both light level switching and presence detection.

Based on this analysis, the payback estimate for WIPAM (pre-rebate), given a \$0.125/ kilowatt hour (kWh) electricity price and \$0.75/sq. ft. installed cost, would be 2-5 years for most applications. Higher electricity rates, utility installation rebates, Federal tax credits and other incentives could shorten that payback considerably.

Adura Technologies has productized and commercially launched the Sensor Interface module. The product has been installed in 15 sites.

1.5. Report Organization

The remainder of this report describes the project approach (Section 2.0), the project outcomes (Section 3.0), and Conclusions and Recommendations (Section 4.0).

2.0 Project Approach

Adura Technologies performed market research and developed the WIPAM system. The CLTC reviewed Adura's market and economic analysis and drafted sensor specifications and field tested the WIPAM system.

Project Task List

| |
|--|
| Market Analysis and Development of WIPAM Product Specification |
| Photosensor Motherboard Prototype Development |
| Photosensor Prototype Housing & Mounting Evaluation |
| Motion Sensor Motherboard Prototype Development |
| Motion Sensor Housing & Prototype Mounting Evaluation |
| Develop Control Algorithms for Heterogeneous System |
| Preproduction Prototype Construction and Evaluation |
| WIPAM Field Testing |
| Market Connections Activities |

2.1. Market Analysis and Development of WIPAM Product Specification

In December 2008, Adura Technologies completed a comparative analysis of existing wireless occupancy sensors and photocells.

For photocells, a number of innovative devices were found both for devices that were designed to provide coverage for a small area and for self-powered devices.

- No technical barriers were found to providing a self-powered photocell that met the requirements of the application. For the one dedicated self-powered device, the transmission interval was found to be satisfactory for the application.
- The project team found that for devices powered by photovoltaics (PV) that the size of the PV drove the size of the product. Products with PV tended to be larger than comparable devices that were wired to a power supply.
- Aside from the requirements of the PV, the team found that a small device can provide the desired coverage.
- From the information provided by almost all of the manufacturers, the team was unable to determine if the photocells provided a meaningful representation of the light level.
- Where third-party test information was available, the project team found the test results provided different information than the manufacturers provided.
- Many devices were found that combined both occupancy sensing and light sensing in one device. While the team found nothing wrong with this concept, a distinct lack of specifications for the light level sensing was found.
- To meet the requirements of Title 24, the project team believes that a silicon photodiode is the required sensing technology.

- The project team found that for an off-axis viewing angle presenting the spatial sensitivity was difficult and the benefit may not offset the challenges.
- For occupancy sensors, a number of promising technical advances were found:
- While it appears quite viable to create a wireless occupancy sensor, the project team was unable to find a single product available from one of the major manufacturers.
- It is believed that these innovative products constitute a tiny percentage of the occupancy sensor market in the United States. The one target market that appeared to have multiple offerings was solutions targeted for hotel occupant room control.
- The team found that coverage of an adequate area could be provided in a small enclosure.
- Among the occupancy sensors studied, there was less standardization in describing the occupancy sensing coverage areas than is typical of more traditional U.S. occupancy sensors. The project team found more variation in the way that European manufacturers present this information.
- It was found that a variety of battery options have been employed to power occupancy sensors. Also, a tremendous variation was found in estimated battery life from one year to greater than five years.
- The project team found that the most viable technology for a low powered device was a passive infrared sensing technology.

This analysis can be found in the report *Comparative Analysis of Photocells and Occupancy Sensors*¹. In this report, the required specifications for these two products were described.

2.2. Photosensor Motherboard Prototype Development

Adura developed a printed circuit board that utilized a processor, ZigBee² radio, a light-sensing chip that communicated digitally with the processor, and a battery. This device transmitted light level values to the Adura wireless network. Lab testing showed reliable performance. The results of this test showed the concept was viable. Battery life was projected at three years.

2.3. Photosensor Prototype Housing and Mounting Evaluation

In evaluating photocell housing and mounting, Adura investigated the following key areas:

- Options to purchase plastic housing that was already being manufactured to avoid the cost of designing new plastic and to speed up the product development time.
- Whether the photocell and the occupancy sensor could have a similar look so they were recognizable as one product family; yet each product could successfully meet its individual performance requirements.

¹ Do, Alex, Douglas, Paton. 2008. *Comparative Analysis of Photocells and Occupancy Sensors*, California Energy Commission, PIER Buildings End-Use Energy Efficiency Research Program. See Appendix A.

² ZigBee is a low-cost, low-power, [wireless mesh networking](#) standard.

- Investigation of space requirements, aesthetics, possible panel sizes, and configurations as well as mounting options for one or more photovoltaic panels.
- Possible configurations of the optic elements to provide the desired spatial sensitivity.
- The options for providing a replaceable battery, how big the battery had to be, and how the battery could be field accessed to be replaced.

Adura identified or created strong solutions to each of the individual areas. However, the researchers were unable to identify a solution that satisfied all of the objectives that did not require designing a new plastic enclosure.

2.4. Motion Sensor Motherboard Prototype Development

Adura developed a printed circuit board that utilized a processor, ZigBee radio, a passive infrared sensor and a battery. This device transmitted occupancy signals to the Adura wireless network.

While energy harvesting methods were thoroughly researched and initially tested, it was determined that the cost benefit of existing technologies did not justify adding energy harvesting. One consideration was that the requirement for a battery could not be avoided due to the requirement to perform under sustained low or no light conditions. Battery life was projected at three years.

Lab testing was done in accordance with the National Electrical Manufacturers Association (NEMA) WD-7 occupancy sensing standard³. Lab testing showed performance that equaled or exceeded commercially available passive infrared occupancy sensors.

2.5. Motion Sensor Housing and Prototype Mounting Evaluation

Adura evaluated existing plastic housing that was available for purchase. Adura completed a buying arrangement for a surface mounted enclosure suitable for a wireless occupancy sensor. This enclosure utilized a high performance Fresnel lens mounted at a standard focal length. The performance results of mounting the prototype board within this plastic housing equaled or exceeded the performance of commercially available passive infrared occupancy sensors.

Adura found that the enclosure requirements of a wireless occupancy sensor did not align with existing industry standard enclosures. First, the number of individual components was reduced. Thus, much of the space available on the printed circuit board was not required. Second, the battery required a taller enclosure. In addition, the battery required an access panel to replace the battery in the field.

2.6. Develop Control Algorithms for Heterogeneous Systems

This task became a focus of the development effort for several reasons:

³ <http://www.nema.org/stds/wd7.cfm> - standard provides the definition and measurement of characteristics relevant to the use and application of occupancy motion sensors of passive infrared and ultrasonic types.

- Adura found an immediate need to incorporate occupancy-based control and daylighting control into the wireless control network.
- Adura encountered obstacles (described above) to creating wireless occupancy sensors and photocells.
- Adura found that existing standard design practice favors the use of dual technology occupancy sensors in classrooms and larger offices. Dual technology sensors combine passive infrared sensing with another technology that better detects small motion. The second technology can be ultrasonic or sound detection. In exploring the need for a second sensing technology, the project team found that the power requirements for ultrasonic as an active technology were too high to operate on a battery. Also, sound detection was not pursued as an option because of a lack of success with initial inquiries into licensing the technology from the patent holder.
- Many facilities have an existing investment in occupancy sensors, and there would be great benefit to integrating these devices into the wireless control network.

Adura set its focus on creating a device that would integrate existing occupancy sensors and photocells into the wireless network. This device was named the Sensor Interface. In addition to creating the physical device, much of the algorithm development involved this device.

The sensor interface is designed to mount above a ceiling and be powered by the same power pack that supplies the occupancy sensors. The sensor interface is designed to mount onto an electrical junction box. The sensor interface is plenum-rated, and the low voltage wiring connections do not have to be enclosed within an enclosure. The method of installation and wiring is intended to match common electrical installation methods.



Figure 1. Sensor interface

Photo Credit: Architectural Energy Corporation

In connecting the occupancy sensors and photocells to the Sensor Interface, Adura followed key tenets to develop its control principles:

- Move as many of the adjustment parameters into the wireless control network and away from adjustments made at the physical device. As an example with occupancy sensors, this meant that the time delays set at the occupancy sensor were to be set to their minimum, while an additional time delay was created in the wireless control network. The benefit of this is that the time delays are remotely adjustable. In fact, they can be automatically adjusted based on the expected use of the building. During working hours, the time delays in an office could be set for 30 minutes. After hours, when only the cleaning crew is expected, the time delays could be set to 5 minutes.
- The decision making should be made in the individual controllers, and the signaling device should be just a signaling device. The advantage of this principle is that multiple devices can receive the same information from a signaling device, and each uses the information in its own way. For example, an occupancy sensor may signal occupancy for both a cubicle and a hallway. The cubicle lights may utilize a shorter time delay and reduce their level sooner than the hallway lighting, which may have a longer time delay to provide safe egress. Similarly, the light level readings from one photocell can be used by multiple lighting fixtures each with its own set point.
- Integrating signaling devices into a wireless network allows for innovative strategies that are more difficult to implement with a wired control system. As an example, with a wireless control network, transition scenes can be created that provide reduced lighting instead of turning completely off as a typical occupancy sensor would turn off the lights at the end of the time delay. The transition scene will turn off a portion of the lights in an area to provide a warning that the lights are about to turn off.
- Each controller can evaluate multiple control signals and respond to the most appropriate signal. For instance, a controller can receive an occupancy signal as well as a light level signal and decide whether there is enough daylight to not turn on the lights or to turn them on at a reduced level. In addition, each controller may respond to additional stimuli such as wall switches, automatic schedules, and demand response events and then determine the correct behavior.

Adura has completed work on the control function integration in a highly distributed network.

2.7. Preproduction Prototype Construction and Evaluation

Adura evaluated the Sensor Interface product with a variety of commercially available occupancy sensors and photocells for signal compatibility and control response. Lab test results showed compatibility with the standard devices manufactured by all of the major U.S. lighting controls manufacturers.

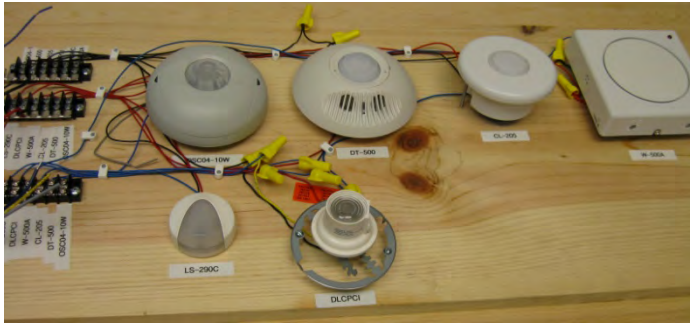


Figure 2. Lab test configuration

Photo Credit: Architectural Energy Corporation

2.8. Field Test

The project team continues to field test of Adura's wireless control system, known as the Adura LightPoint System (ALPS), at the CLTC facility in Davis, California. A WIPAM system demonstration also took place in a parking garage at the University of California, Santa Barbara.

2.8.1. CLTC Demonstration

This demonstration showcases the wireless control system in a corridor application. The control system communicates wirelessly by using radio frequency (RF) technology. It conforms to the ZigBee open standard communicating at a frequency of 2.4 gigahertz. The control network consists of the following components.

- **10 Light Controllers.** Installed inside of 10 lighting fixtures, the controllers are Adura's model LC-1RD. Each controller has one relay for on/off control and a 0- to 10-volt (V) direct current (DC) dimming signal for connection to dimming ballasts. Each light controller provides several key functions:
 - Each light controller acts as a state machine making a decision on the appropriate level of the lights based on the received signals and automatic schedules stored on board.
 - Each light controller acts as a repeater in the mesh network. Each light controller listens and repeats messages to create a robust network.



Figure 3. Light controller

Photo Credit: Architectural Energy Corporation

- **2 Sensor Interfaces.** One of these devices is connected to two industry standard occupancy sensors. The other Sensor Interface is connected to an industry standard photocell. The sensor interfaces and sensors are powered by industry standard power packs. The Sensor Interface shares the occupancy signal with the wireless network.



Figure 4. Sensor interface

Photo Credit: Architectural Energy Corporation

- **2 Wall Control Interfaces.** Each Wall Control Interface is connected to a standard decorator wall switch. The wall switches are used to adjust the automatic settings.



Figure 5. Wall control interface

Photo Credit: Architectural Energy Corporation

- **1 Gateway.** The gateway connects the lighting system network to the Internet.



Figure 6. Gateway

Photo Credit: Architectural Energy Corporation

- **Video terminal.** The terminal displays Adura's dashboard running on a standard Web browser.



Figure 7. Adura component display at CLTC test site

Photo Credit: Architectural Energy Corporation

The CLTC ALPS demonstration at CLTC takes place in two corridor zones, the classroom corridor and restroom corridor, with the system in both zones commissioned for bilevel operation (i.e., fixtures are commissioned to operate at two power levels and corresponding light levels to address both high and low occupancies). Figure 8 shows the floor plan of the corridors, and Figure 9 shows the two corridors with the system installed.

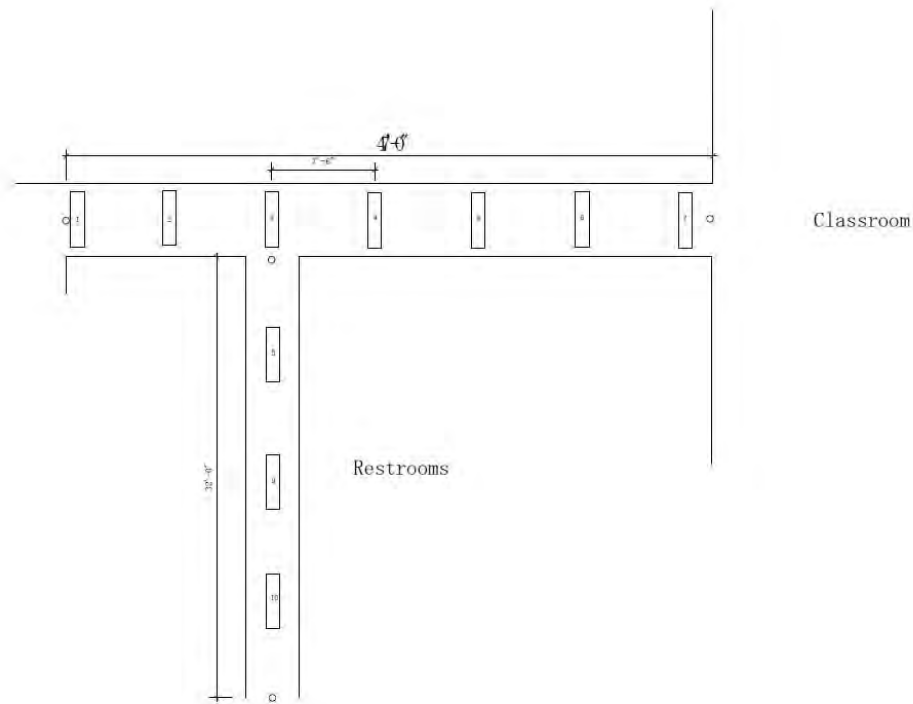


Figure 8. Floor plan of CLTC demonstration

Photo Credit: Architectural Energy Corporation

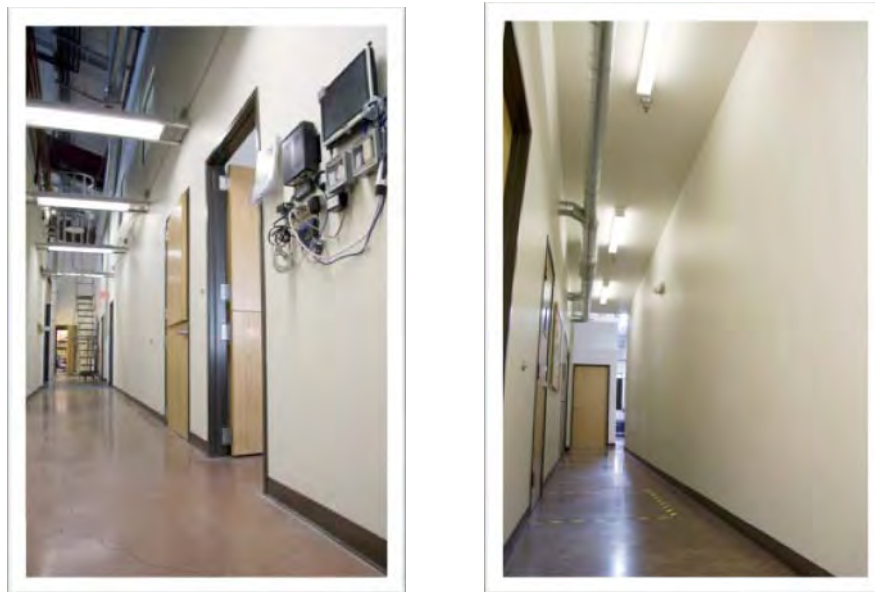


Figure 9. System installed in classroom corridor (left, new construction) and restroom corridor (right, retrofit)

Photo Credit: Architectural Energy Corporation

The classroom corridor demonstrates the ALPS in a new construction setting, and the restroom corridor demonstrates the system's retrofit capabilities. The new construction corridor is

outfitted with new fixtures that have dimming ballasts for bilevel capabilities. The retrofit option required a ballast replacement to allow for the bilevel features. After evaluating the different design options, Adura and CLTC decided to use 0- to 10V dimming DC ballasts and light controllers in the demonstration corridors. Figure 10 shows the light controller and ballast wiring. Adura's LC-1RD controller allows the team to specify any combination of light levels for occupied/unoccupied states and allows the system to perform gradual transitions between occupied and vacant states. Gradual transitions are more aesthetically pleasing than sudden shifts in light levels. The ballast dimming capability allows for the fixtures in the demonstration to respond to daylight levels and maintain a constant light level in the space.

Wiring Diagram

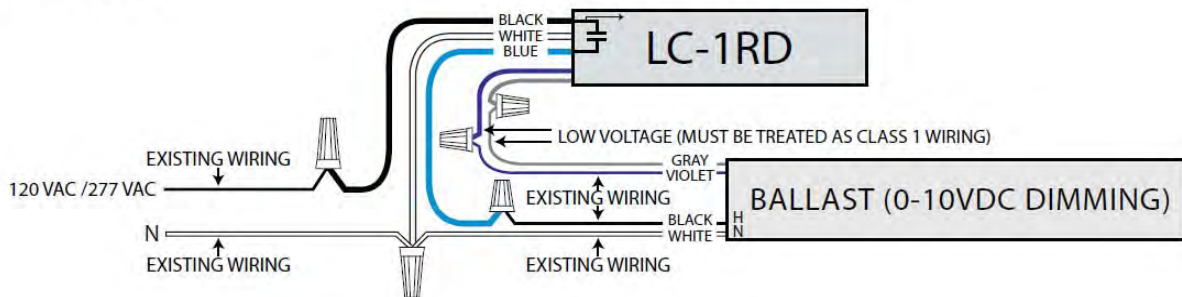


Figure 10. Light controller and ballast wiring configuration

Source: Architectural Energy Corporation

The Adura team commissioned the ALPS demonstration at the CLTC to run at approximately 30% of total load when the space is vacant and at approximately 70% of total load when the space is occupied. The team accomplished this by installing third-party occupancy sensors paired with Adura Sensor Interfaces in each hallway and creating two zones during the commissioning process. Zone 1 included all fixtures and sensors in the classroom corridor, and Zone 2 included all fixtures and sensors in the restroom corridor. Thus, users can activate lighting in each hallway separately even though lighting in both corridors is controlled by components on the same network.

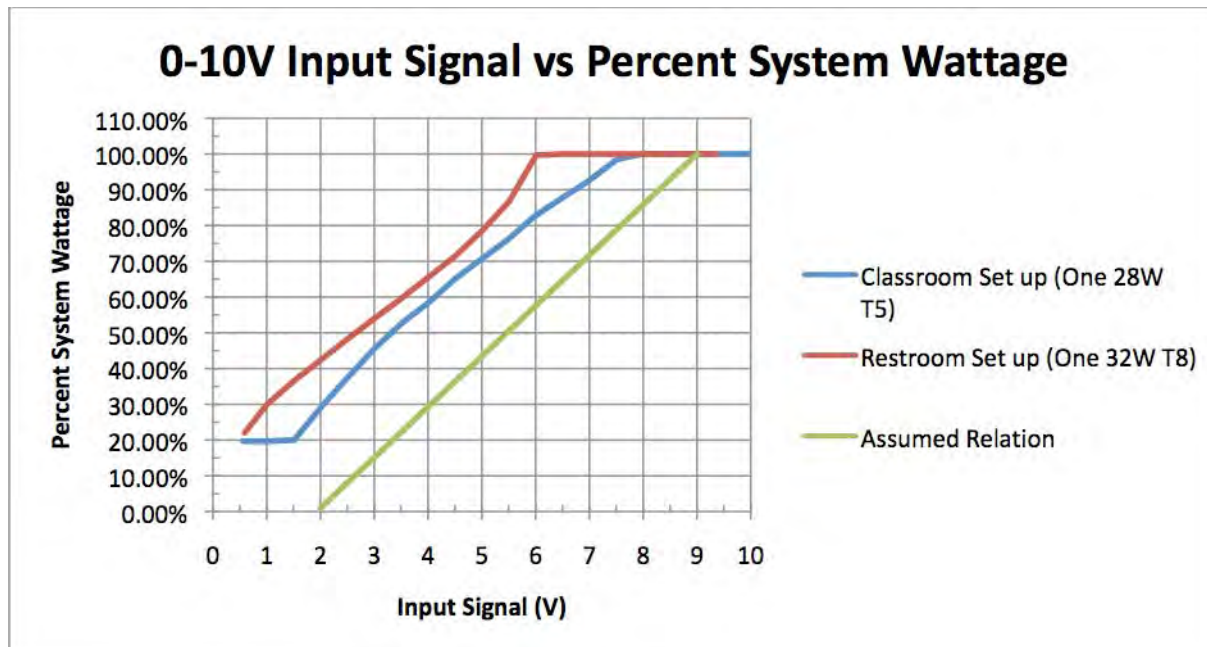
The Gateway functions as a data collector, enabling the “Energy History” graphical interface in the online access account for Adura Technologies customers. Gateway installation also allows for remote system access, so Adura personnel can troubleshoot problems.

The system was started up and programmed by Adura personnel. A computer application with a graphical user interface is under development. Lighting control systems reduce lighting energy consumption. The Adura system in the CLTC demonstration reduces energy consumption by adjusting power consumption and correlated light levels.

The CLTC demonstration system has 10 fixtures operating in two separate zones. As mentioned above, the two zones represent new construction and retrofit applications. The new construction application uses recessed T5 fixtures from Lithonia; the retrofit application uses existing linear T8 fixtures.

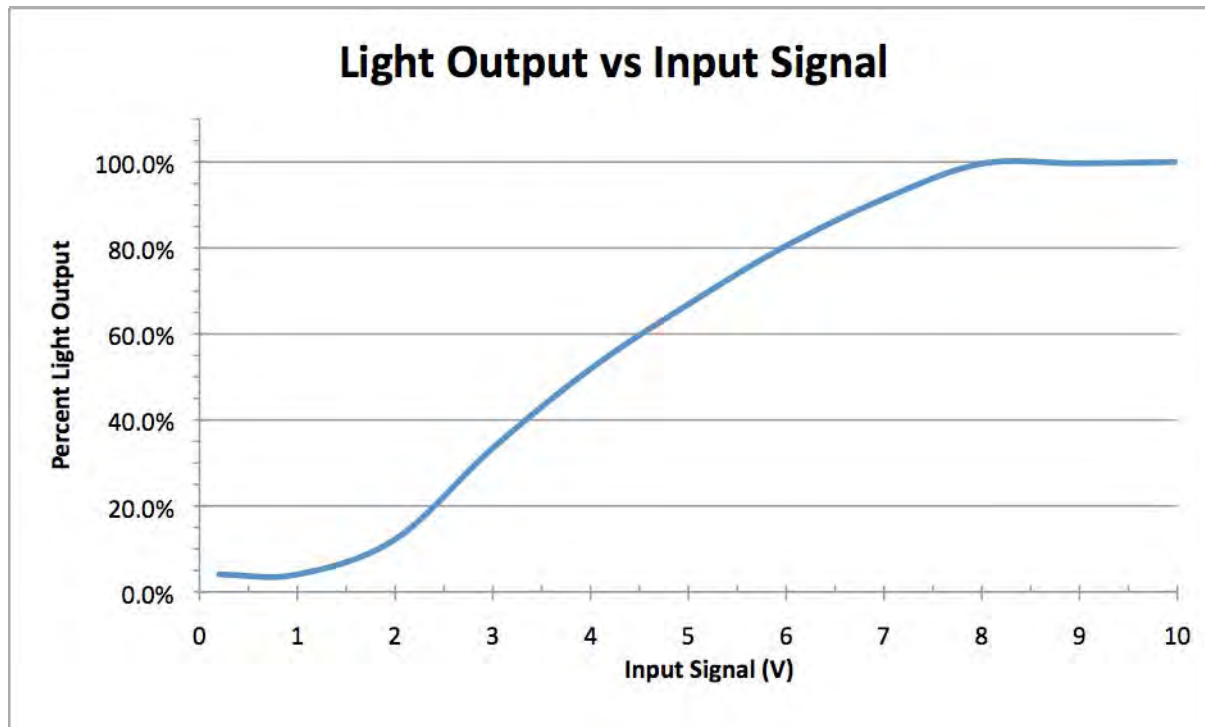
The RT5 and T8 fixtures have different system characteristics related to their ballast-lamp pairings; specifically important to the controls aspect of the ALPS are their power and light output responses to the 0- to 10V input signal. Based on Adura factory default specifications, the light controllers are designed to run fixtures at 1% power at a 2V input and 100% power at 9V input. Table 4 shows the relation of power consumption to the 0- to 10V signal for the CLTC demonstration. The “assumed relation” plot in this figure shows the input-power relation and also shows that ballast-lamp system returns an individualized power consumption curve. Commissioning must take this scaled relation into account to achieve the user’s desired light or power consumption levels.

Table 4. 0- to 10V input signal related to power consumption



Source: Architectural Energy Corporation

Table 5. 0- to 10V input signal related to light level output for RT5 fixture



Source: Architectural Energy Corporation

These relationships are significant when determining the actual savings that the control system achieves. During this installation, manual adjustment of the input signal was performed during the commissioning process. Adura is developing automated mapping for future implementation.

The CLTC demonstration system specifies power consumption levels for occupied and unoccupied conditions. For the new construction corridor, the scaling described above changed the input signal from the 4V assumed relation to 2V for the unoccupied state and from 7V to 5V for the occupied state. The retrofit corridor was commissioned to 1V and 4.5V. These commissioning adjustments result in approximate 30% (unoccupied) and 70% (occupied) power consumption.

2.8.2. UC Santa Barbara Demonstration

The project team demonstrated the WIPAM system at the 2009 University of California/California State University/California Community College Sustainability Conference at the University of California, Santa Barbara, on the second level of a parking structure. The structure previously used 150-watt (W) (170-W system wattage), high-pressure sodium canopy luminaires.



Figure 11. UCSB parking garage existing fixtures

Photo Credit: Architectural Energy Corporation

All luminaires operated 24 hours a day, 365 days a year. The goal of this retrofit project was to demonstrate cost-effective perimeter daylighting. Because of the existing circuit configurations at the site, a traditional wired photosensor controlling all circuits serving the daylighting zone would extinguish too many interior garage luminaries, resulting in scenario dark interior conditions with light levels below standards. To avoid costly rewiring and demonstrate a cost-effective solution that achieved project goals, the demonstration team replaced 10 perimeter high-pressure sodium luminaires with deck-mounted bilevel induction fixtures equipped with Adura wireless daylighting systems. The new fixtures used were 70-W Everlast® induction step-dimming garage luminaires.



Figure 12. UCSB parking garage retrofitted fixtures

Photo Credit: Architectural Energy Corporation

The Adura system consists of a Light Controller installed inside of each of the 10 fixtures. It also includes one Sensor Interface connected to an industry standard photocell.

The control system consisted of individual occupancy control and daylighting control across a zone. When adequate daylight is sensed, the fixtures turn off. When there is not adequate daylight and no occupancy, then the fixtures are on at 50%. If occupancy is sensed, then the fixtures go to 100%.

The initial annual energy use prior to the retrofit was 14,893 kWh. The annual energy use after the retrofit was 2102 kWh or an energy consumption reduction of 86%. This translates to annual energy savings of about \$1,600 and a simple payback period of six years.

2.9. Market Connection Activities

Adura has productized the Sensor Interface and is currently manufacturing and selling the Sensor Interface in California and other parts of the United States as part of the Adura system offering.

Additional activities included development of marketing collateral and participation in various conferences and trade shows, including LightFair 2010. Also, a short video was developed featuring the corridor demonstrations at the CLTC and is available on several LCF participant websites.

2.10. Project Outcomes

The WIPAM system is expected to reduce installation and commissioning time by as much as 50% over standard industry practice for competing lighting control technologies and could

reduce office lighting energy use by as much as 25%. A typical installation is depicted in Figure 13.

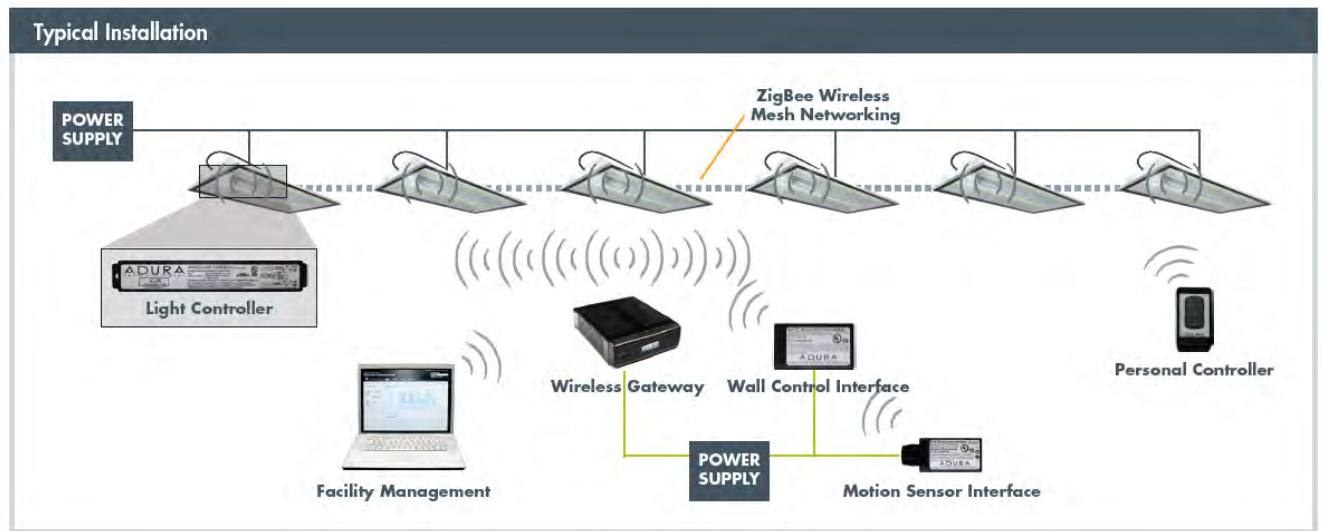
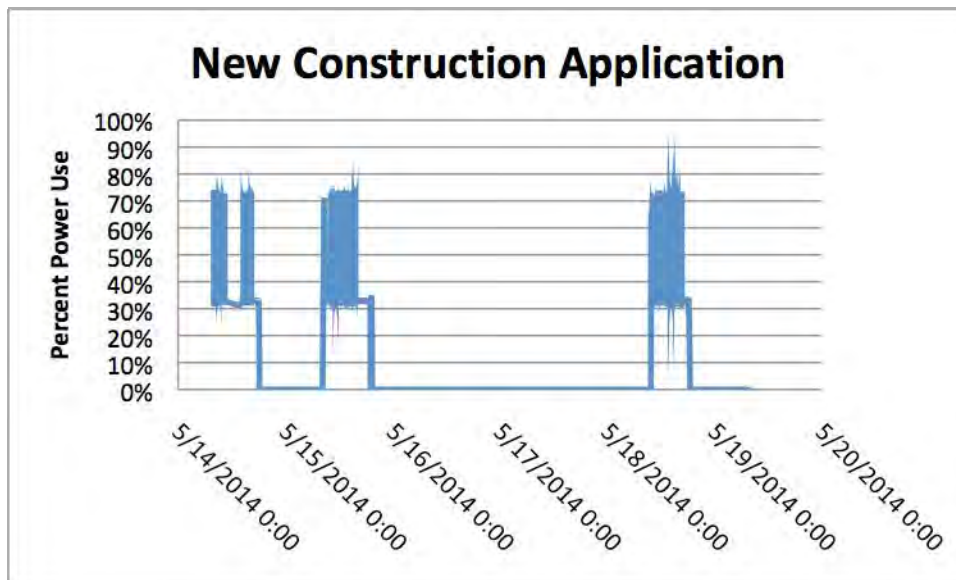


Figure 13. WIPAM system configuration

Source: Architectural Energy Corporation

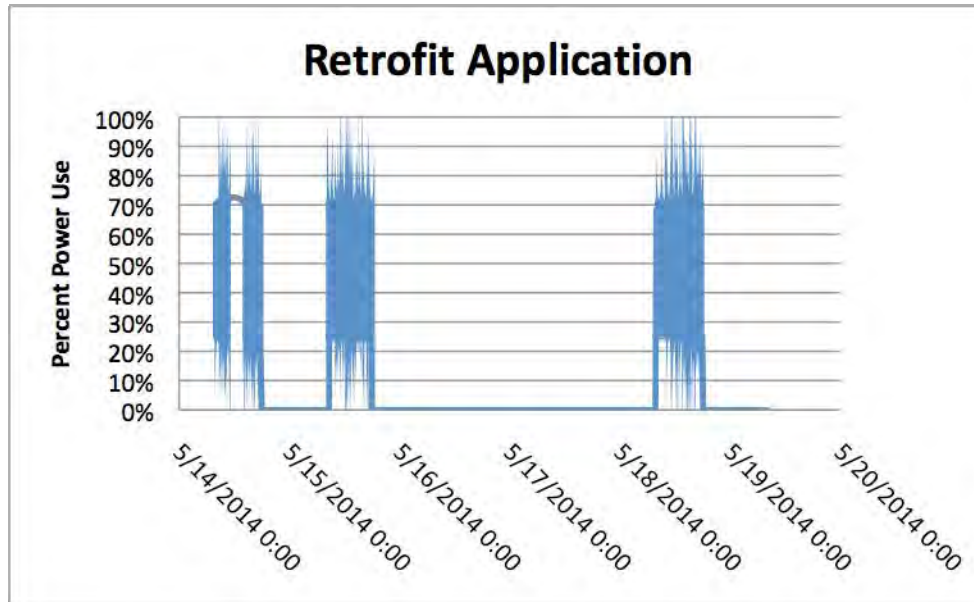
Table 6 show examples of actual data from the CLTC demonstration. The extended 0% use is during the weekend.

Table 6. Example of new construction corridor energy use



Source: Architectural Energy Corporation

Table 7. Example of retrofit corridor energy use



Source: Architectural Energy Corporation

The savings can be calculated by comparing the total load of both zones (323 watts) to the load of the controlled system for the same time-of-use periods, using the following equation:

$$\text{Energy Consumption (in kilowatt hours [kWh])} = \text{Load (in kilowatts [kW])} \times \text{time-of-use (in hours)}$$

Tables 8 and 9 show the savings calculation results from the field test.

Table 8. Lighting energy use calculation

| Baseline | Fixture Wattage (kW) | Number of Fixtures | Hours Per Day | Days Evaluated | kWh |
|------------------|-----------------------|--------------------|---------------|----------------|------|
| New Construction | 0.0325 | 7 | 10 | 3 | 6.83 |
| Retrofit | 0.0318 | 3 | 10 | 3 | 2.86 |
| | | | | Total: | 9.69 |
| W/Controls | Fixture Wattage (kW) | Number of Fixtures | Hours Per Day | Days Evaluated | kWh |
| New Construction | From Data (Figure10) | 7 | 10 | 3 | 2.36 |
| Retrofit | From Data (Figure 11) | 3 | 10 | 3 | 1.17 |
| | | | | Total: | 3.53 |

Source: Architectural Energy Corporation

Table 9. Control system savings calculations

| Savings Calculations | (for the 10 demo fixtures) |
|-----------------------------|---|
| 2.05 | kWh saved for demo area/day |
| 492.70 | Annual kWh savings (Based on 240 workdays/year) |
| \$0.13 | Average kWh rate |
| \$61.59 | Annual savings |
| \$1,387.22 | System Cost |
| 63.58% | System Savings (Energy) |

Source: Architectural Energy Corporation

The bilevel corridor demonstration saves 64% compared to the energy that would be used by the same 10 fixtures at 100% power running an estimated 10 hours each workday.

Table 10 shows each corridor individually, which allows for a comparison of occupancy rates.

Table 10. Occupancy/vacancy related to energy savings

| Corridor | High Occupancy (70%) | Low Occupancy (30%) | Energy Savings |
|--------------------|-----------------------------|----------------------------|-----------------------|
| CLTC Demonstration | * | * | 63.6% |
| New Construction | 6.1% | 93.9% | 65.4% |
| Retrofit | 36.0% | 64.0% | 59.3% |

*From data – combined new construction and retrofit corridor data

Source: Architectural Energy Corporation

Based on an average of three work days, the bilevel corridor application of occupancy/vacancy controls is expected to save between 60% and 65%. Lower-occupancy applications will save even more.

3.0 Conclusions and Recommendations

3.1. Conclusions

The Adura field test has demonstrated 64% energy savings from implementing advanced control strategies over baseline conditions in new construction and retrofit applications.

3.2. Commercialization Potential

The Sensor Interface product has great commercial potential because it leverages commonly available products and extends their benefits into advanced wireless control systems. Adura has released this product for sale. It is currently being sold as part of Adura's system offering.

3.3. Recommendations

The field test identified some technological refinements to improve the setting up and energy reporting of the Adura system:

- It would be useful to be able to analyze the lamp-ballast system to which a light controller is connected, which would allow for individualized responses to the voltage input signal. This would entail automated mapping of DC voltage output to power wattage.
- It would be useful to be able to specify system settings based on power usage in addition to light output.
- For system scheduling, transitioning between normal work time and energy saver settings needs to be refined to address situations such as ensuring that the system makes the scheduled transition even when a space is unoccupied at the scheduled transition time.

Adura should continue to look at opportunities to create a wireless occupancy sensor and a wireless photocell either through partnering with another manufacturer or creating these products themselves. The wireless products, while not applicable to all spaces, would further open opportunities for installing lighting controls in spaces that are challenging to install with wired devices.

Adura Technologies should continue to identify enabling technologies that can extend the cost effective reach of advanced lighting controls. With specific regard to this project, new technologies will allow the creation of wireless occupancy sensors and photocells. For both devices, these advancing technologies include lower power radio transmission standards, new battery technologies, and lower cost of energy harvesting components. For occupancy sensors, the advancing technologies include lower power technologies that sense small motion. For photocell, the advancing technologies include new light-sensing chips.

3.4. Benefits to California

Benefits to California from commercialization of the WIPAM system include reduced start-up cost and improved reliability of commercial lighting controls, which would lead to their wider

adoption and more reliable use. This would substantially reduce lighting energy use in new and existing buildings.

Applications for the system include small offices, corridors, and parking garages. The Adura team researched addressable floor space in various California commercial buildings. They calculated the addressable floor space for the WIPAM system to be 540 million square feet or 10% of floor stock. Using the amount of addressable floor space and assuming 5% market penetration with energy savings of 50%, the potential benefit is estimated to be more than 50 MWh per year. Demand savings are more difficult to assess since this technology is used to lower light levels during low or zero occupancy and return the lights to higher levels when presence is detected.

Glossary

Specific terms and acronyms used throughout this document are defined as follows:

| Acronym | Definition |
|----------------|---|
| ALPS | Aura LightPoint System |
| CLTC | California Lighting Technology Center |
| DC | direct current |
| HID | high-intensity discharge |
| kW | Kilowatt |
| kWh | Kilowatt hour |
| LCF | Lighting California's Future |
| MWh | Megawatt hour |
| NEMA | National Electrical Manufacturers Association |
| PIER | Public Interest Energy Research program |
| PV | Photovoltaics |
| RF | radio frequency |
| US | United States |
| V | Volt |
| W | Watt |
| WIPAM | wireless integrated photosensor and motion sensor |

**Appendix A: Comparative Analysis of Photocells and Occupancy
Sensors Report (PDF will be added)**

Attachments: Sensor Interface Datasheet



Wireless Sensor Interface



P/N SI-2C

Adura provides a powerful energy management and wireless lighting control platform that can scale from the management of a few lights to the control of an entire campus or commercial building.

Adura's Sensor Interface adds wireless capability to industry standard low voltage occupancy sensors and photo sensors. This provides flexible control zoning and the ability to incorporate multiple control strategies in a cost-effective manner. Occupancy sensing and daylighting can be combined with other control strategies, such as smart scheduling, demand response and wall control.

Installation, setup, programming and maintenance are simple. The Sensor Interface snaps into an electrical junction box and includes LEDs to indicate sensor status as feedback during installation. Setup is completed by creating lighting control zones and applying control strategies, using Adura System Designer.

The Sensor Interface incorporates wireless RF technology using the ZigBee® standard for fail-safe communication. By forming a self-healing, adaptive mesh network that maintains connectivity, communication is assured even in difficult environments.

Examples of Applications

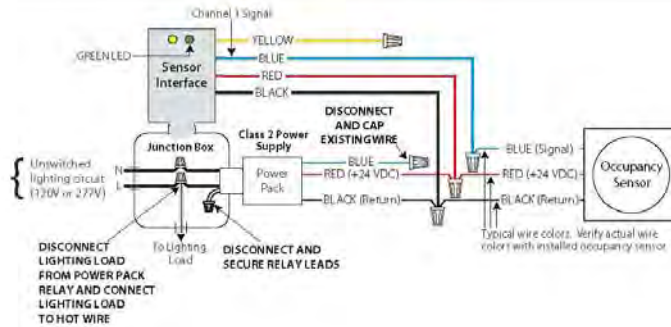
- Office Buildings
- Schools (K-12)
- Retail Facilities
- Campuses
- Warehouses
- Parking Garages

Features

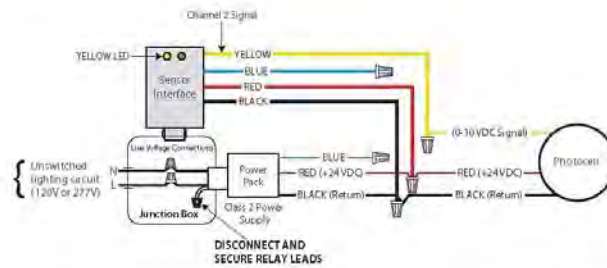
- Connects to existing occupancy sensors, taking advantage of an existing investment while transitioning to Adura's more adaptable lighting control system
- Two independent channels to monitor multiple standard occupancy sensors or photo sensors
- Interfaces with commercially available low voltage occupancy sensors (ultrasonic, PIR or dual technology), as well as photocells (0 - 10 VDC)
- Transmits data from the occupancy and photo sensors onto Adura's wireless network
- Non-volatile memory for sensor settings
- Inputs are protected against over-voltage and surges
- Powered by a Class 2 power supply, such as a 24 VDC power pack
- Suitable for mounting on an electrical junction box
- UL 2043 (plenum rated) listed
- Compliant with FCC Part 15
- 5 year warranty

Wiring Diagrams

Occupancy Sensor



Photocell



Dimensions



Specifications

| | | | |
|--|--------------------|---|--|
| Input Voltage | 15 - 30 VDC | Wires | 9" 600 VAC plenum rated, 18 AWG solid conductors |
| Power Consumption | 11 mA | LEDs: Green channel 1 Yellow channel 2 | Steady = contact closure (motion detected) Blinking = 0 - 10 VDC signal (photocell) |
| Sensor Input Channels | 0 - 30 VDC | Operating Environment | 40 to 140 deg F, dry location or 4 to 60 deg C |
| Enclosure | Recyclable plastic | Memory | Configuration programming stored in non-volatile memory |
| Radio Frequency | 2.4 GHz | Mounting | Snaps into a 1/2" knockout on electrical box |
| RF Transmission Output Power (Average) | +12 dBm | | |

Ordering Information

| Catalog Number | Description |
|----------------|-------------------------------------|
| SI-2C | Sensor Interface - 2 Input Channels |

MKT-000012, R1

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